

***Geocoris punctipes* as a predator of *Bemisia tabaci*: a laboratory evaluation**

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Abstract

Geocoris punctipes (Say), a predaceous lygaeid not previously documented as a whitefly predator, was tested in the laboratory as a natural enemy of the sweet potato whitefly, *Bemisia tabaci* (Genn.). Its stalking behavior with whiteflies as prey was similar to that observed with aphids. A previously unobserved behavior was noted that involves the predators using salivary secretions to fasten the wings of prey to various surfaces, allowing labial probing and feeding. Prey consumption as a function of prey number appeared to follow the pattern of the Holling type II functional response. Handling time per prey item ranged from about 180 to 240 seconds. No changes were observed in handling time devoted to earlier versus later catches. Nutritional quality of whiteflies was measured using crude protein, lipids and carbohydrates as criteria. Performance, in terms of predator behavior, total daily handling time, functional response, energy budget and nutritional quality all support the hypothesis that *G. punctipes* is a promising candidate for biological control of sweet potato whiteflies.

Introduction

The sweet potato whitefly, *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae), is a pest of worldwide importance attacking crops in agricultural settings as well as those grown under protected cultivation (Byrne *et al.*, 1990). It damages plants in three ways: large populations can extract enough phloem sap to directly affect yield (Pollard, 1955); it serves as a vector for several viral pathogens (Muniyappa, 1980) and its honeydew (excreta) interferes with picking and ginning operation (Hector, 1989) and serves as a medium for sooty mold fungi (e.g. *Capnodium* spp.) that interfere

with photosynthesis (Perkins, 1983). These facts indicate a great need for effective control strategies. The resistance of whiteflies to insecticides has rendered chemical control ineffectual (Prabhaker *et al.*, 1985; Ditttrich & Ernst, 1990). A search for alternative control strategies leads inexorably to an examination of the potential of whitefly natural enemies as biological control agents. While a great deal of information is available concerning the impact of parasitoids on whitefly populations (van Lenteren & Woets, 1988; Bellows & Arakawa, 1988; Gerling, 1990; Onillon, 1990) much less is known about the potential of predators as biological control agents.

Among the predators that have been reported are 12 mite species, several coccinellids (Gerling, 1990) and a chrysopid (Butler & Henneberry, 1988). Fewer species of hemipterans have been reported as whitefly predators, with disappointing results (Ekbohm, 1981). Evidence of hemipterans' ability as effective generalist predators in several agroecosystems is well documented (Cohen, 1990 and 1991) and suggests that they may be effective as whitefly predators under appropriate conditions.

In previous studies of predation on whiteflies, Ekbohm (1981) found *Anthocoris nemorum* (Heteroptera: Anthocoridae) to be unsatisfactory as a predator of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood). She concluded that *A. nemorum*, which is generally regarded as an aphid predator, does not kill sufficient numbers of whiteflies to control these pests in glasshouses. In contrast, Butler and Henneberry (1988) found larval *Chrysoperla carnea* (Stephens) to be acceptable predators of the egg and nymphal stages of *B. tabaci* under glasshouse conditions. To our knowledge, predators of adult whiteflies have not been examined. Because it is important to control all stages of these pests, it is appropriate to identify potential natural enemies of adults. In this vein, it is important to identify the indigenous natural enemies of whiteflies so that they can be conserved and encouraged. Also, since augmentative programs may also play an important future role in management of whiteflies, it is crucial to assess the potential of those natural enemies that can be successfully reared on a mass scale.

In efforts to assess the effectiveness of laboratory-reared predators (Cohen, 1990), it was found that *Geocoris punctipes* (Say) (Hemiptera: Lygaeidae) were adept at capturing *B. tabaci* adults. This raised questions regarding the potential of *G. punctipes* as a predator of whiteflies and prompted this study of its fitness as such and the reciprocal suitability of *B. tabaci* as prey. This study is intended as a screening of predators for their potential use in field or glasshouse situations where whiteflies are a serious pest. For criteria we used feeding behavior, rates of prey consumption,

prey handling time and the nutritional benefits acquired by *G. punctipes* when it utilizes *B. tabaci* as prey. We restricted the study to adult predators and adult prey in the interest of parsimony, considering the several criteria that we chose to evaluate. Preliminary results indicate that *G. punctipes* also feeds upon larval *B. tabaci*, and this merits further study.

Materials and methods

The *B. tabaci* used in this study were cultured in glasshouses on poinsettia, *Euphorbia pulcherrima* (Willd.), cv. 'Lilo'. Most of the *G. punctipes* used in this study were laboratory reared on artificial diet (Cohen, 1985) while some were collected from alfalfa fields on the University of Arizona farm in Tucson, AZ. The need for large numbers of predators required our supplementing laboratory subjects with field-collected predators. Hagler and Cohen (1990) demonstrated identical predatory capabilities of both laboratory and field-derived *G. punctipes*; thus we felt that interchanging predators from both origins was acceptable for our purposes.

Feeding behavior, including prey approach and prey handling, was observed by direct viewing and video recording with a Wild® 420 Makroskop equipped with a JVC video camera and recorder. Previous observations (Cohen, 1991) of *G. punctipes* feeding on pea aphids, *Acyrtosiphon pisum* (Harris), were used as standard comparisons of feeding behaviors.

Adult females that were randomly selected and starved for 24 h were used in determination of prey handling times and consumption rates. They were then placed either in 39 mm diameter Petri dishes or in cylindrical cages (9 mm diameter × 12 mm height) with from one to ten prey. All prey used in these experiments were adult female *B. tabaci* that were determined to weigh $35.2 \pm 8.8 \mu\text{g}$ (mean \pm s.d.). Final postfeeding weights of prey were measured with a Cahn C-31® Electrobalance immediately upon cessation of feeding bouts. The differences between original and final weights were divided by the observed handling times (in

minutes) to give the consumption rates. Handling times were those observed intervals between onset and completion of labial contact between predator and prey (Cohen and Tang in preparation).

Groups of 5, 10, 25 and 50 *B. tabaci* females were caged with a single starved *G. punctipes* female for 24 h periods on poinsettia plants. Control groups of similar numbers of prey were caged without the predator to establish background mortality rates. This experiment was repeated three times. Mortality was observed after feeding periods, and background (natural) mortality was subtracted from predator-caused mortality to establish the functional response.

Gross nutritional value of *B. tabaci* females was determined using Van Handel's (1985 a & b) methods of analysis of lipids and carbohydrates (corn oil and bovine liver glycogen as standards) and Bradford's (1976) method for determining protein concentrations with bovine serum albumen (Sigma Chemical Co., St. Louis, MO). For analysis of each of these nutrient classes, 100 female *B. tabaci* were removed from poinsettia plants, anesthetized with CO₂, weighed to the nearest 10 µg, homogenized in a glass tissue grinder and analyzed. Total lipids were determined with the vanillin-phosphoric acid method (Van Handel, 1985a), total carbohydrates by the anthrone method (Van Handel, 1985b) and proteins with the Bio-Rad reagent (Bradford, 1976), all analyzed spectrophotometrically. Determination of external, hexane-extractable lipids was made by passing hexane (distilled 3 ×) over adult whiteflies that were pre-weighed and held over glass wool in a Pasteur pipette. The wash was made with 500 µl of solvent and repeated 5 times with the same solvent being passed over the insects. Weights of extracts were used in determination of surface lipids, and this value was subtracted from the total lipids determined as described above.

To determine the mean dry mass of female *B. tabaci*, six groups of 25 adults were killed (with CO₂) and weighed to the nearest µg. They were held at 40 °C for 24 h and reweighed hourly to insure that they had reached a stable weight. This low temperature was used to prevent loss of cu-

ticular lipids through melting and evaporation. Such losses would exaggerate the water content of the prey.

Results

Predator feeding behavior. Prior to feeding, most *G. punctipes* manipulated their labia with their forelegs, presumably for cleaning and preparation of their proboscis for feeding. This behavior seems to be a prerequisite to feeding by *G. punctipes*. Next, predators slowly approached the prey with an extended proboscis. Generally, prey made no effort to escape their predators. This failure to flee from approaching predators was often observed with aphids as prey (Cohen, 1990 and Hagler & Cohen, 1990). After making labial contact with prey, predators inserted their stylets, which could be seen moving within the prey's body. This stylet activity was described in detail by Cohen (1989 and 1990) as a process of mechanical and chemical liquefaction and pre-oral digestion.

At certain angles of observation, a stylet flange could be seen on the surface of the prey's body; however, we could not determine if the flange was produced prior to, during or after stylet insertion, nor whether this salivary structure (Cohen, 1990) was used in attacking and securing the prey or as a stabilizing device to cement the labium to the prey. In the latter case, it would provide the predator with a fulcrum so that stylets could be turned and manipulated within the prey's body (Cohen, 1990).

The attack and handling of whiteflies appeared similar to those behaviors observed when pea aphids or second and third instar *Lygus hesperus* (Knight) (Hagler & Cohen, 1990) served as prey. The only difference between predation on whiteflies versus aphids or *L. hesperus* was in the duration of the feeding bout. The feeding time with aphids was ten times longer than with whiteflies. This is attributable to size differences in the two prey types, pea aphids being ca 60 times larger than whiteflies (Cohen, 1989).

G. punctipes occasionally missed their prey as the predators initiated labial contact, allowing

prey to escape. This was also observed with pea aphids as prey. Such misses with whiteflies were most frequent when the initial contact was with the wings. The labial tip and sheath material appeared to skid past the wing surface in such misses, sometimes resulting in the predator being temporarily glued to the surface of the arena.

We also observed a behavior not previously reported for heteropterans and which may help circumvent certain predation difficulties posed by whitefly wings. *G. punctipes* frequently used its salivary sheath material as a 'glue' to fasten prey to stable surfaces. This process required less than 2 s and allowed the predators to probe vulnerable surfaces of the whiteflies without the former escaping before stylets could be inserted and used to anchor the prey. This subduction strategy was observed frequently, though not invariably; and it was evidenced by the large numbers of whiteflies that we found stuck to surfaces such as leaves and Petri dishes. This behavior is noteworthy in light of the fact that *G. punctipes* lack the raptorial forelimbs possessed by some predators.

Functional response. *G. punctipes* killed 2.4 ± 0.68 , 8.8 ± 0.91 , 21.7 ± 0.62 and 35.2 ± 3.94 whiteflies when offered 5, 10, 25, 50 prey items, respectively. These values represent 48.0, 87.5, 86.7 and 72.3% of the total prey offered. The plot of these values appears to fit the type II functional response (Holling, 1966).

Handling time and consumption rates. The mean handling time for *G. punctipes* when feeding on *B. tabaci* was $228 \text{ s} \pm 74.2 \text{ s}$ (Table 1). During that time they consumed a mean of $72.94 \pm 14.1\%$ of their prey. There were no significant differences between the handling time of *G. punctipes* regardless of when the whitefly was accepted ($P > 0.05$) (Table 1), e.g. the handling time for the second whitefly attacked by the predator was not significantly different from that for the sixth whitefly. The same was true of amounts consumed, which did not change throughout the course of the experiment ($P > 0.05$) (Table 1). Consumption rates ranged from 10 approximately 71 to 127 ng s^{-1} with whiteflies as prey. In contrast, Cohen (1989)

Table 1. The mean (\pm S.D.) handling time and mass of prey consumed by *Geocoris punctipes* with *Bemisia tabaci* as prey. In all tests, N = six prey items

Order of presentation	Handling time (in seconds)	Amount consumed (percent)
1	214.4 ± 71.8^1	72.7 ± 15.7
2	191.8 ± 87.7	77.5 ± 11.7
3	247.4 ± 52.0	76.5 ± 9.8
4	221.5 ± 91.3	74.0 ± 18.5
5	226.4 ± 80.7	71.8 ± 13.2
6	232.4 ± 43.6	64.0 ± 24.1
7	272.9 ± 177.3	66.3 ± 13.0
8	249.4 ± 176.7	65.6 ± 10.1
9	256.7 ± 133.4	61.9 ± 23.2
10	206.7 ± 88.6	72.0 ± 5.7

¹ No significant differences found in either handling times or mass of prey consumed as a function of order of prey presentation according to a Duncan's Multiple Range Test (Duncan 1955)

demonstrated a consumption rate of approximately 237 ng s^{-1} with pea aphids as prey. Both sets of values are in regard to wet weights of prey.

Nutritional reward. The mean weight of 25 female *B. tabaci* was $781.2 \pm 32.2 \text{ mg}$. The mean dry

NUTRIENT PROFILES: WHITEFLIES VS. APHIDS

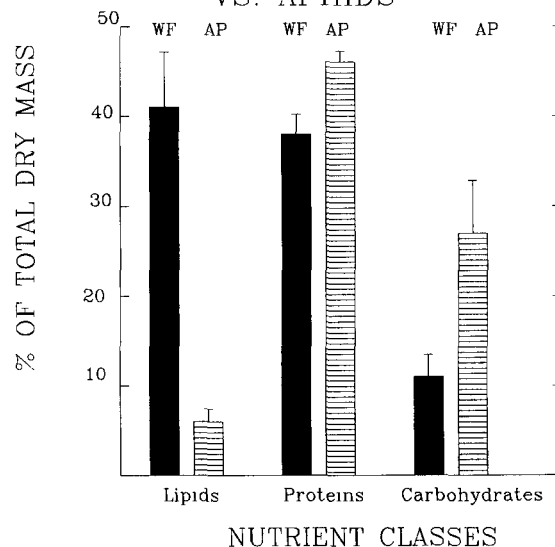


Fig. 1. Nutritional reward present in adult female *Bemisia tabaci* and *Acyrthosiphon pisum*, including percent dry weight of proteins, lipids and carbohydrates (\pm S.E.).

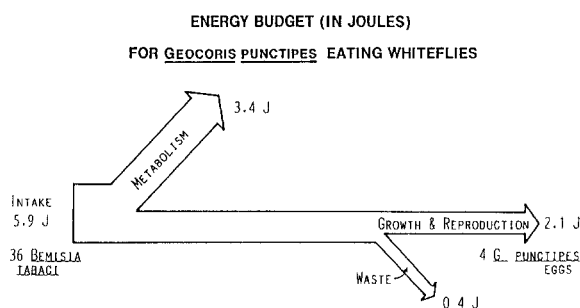


Fig. 2. Daily energy budget for adult female *Geocoris punctipes* feeding on adult female *Bemisia tabaci* (ad. lib).

weight was 282.1 ± 6.3 mg. Thus the percent dry weight composition of an individual *B. tabaci* is $36.14 \pm 1.03\%$. The contents of internal lipid, protein and carbohydrate in adult female *B. tabaci* were 40%, 30% and 11%, respectively (Fig. 1). This figure includes, for comparison, the nutritional profile of pea aphids (Cohen, 1989). A total materials budget for *G. punctipes* feeding on *B. tabaci* is presented in Fig. 2.

Discussion

To suppress a pest population, predators must qualify in certain key regards. First, they must recognize the target species as prey and be capable of readily killing those prey. Second, if predators are present in less than inundative numbers, they must be capable of multiple kills. Third, the interaction must take place in an ecologically reasonable time frame. Fourth, if the predation is to be sustained, there must be a nutritionally ample reward from consuming the prey to support growth, development and reproduction. Our tests of *G. punctipes* using *B. tabaci* adults as prey provide evidence of the fitness of these predators with respect to all four qualifications.

Schoener (1971) stated that gain (G) has to exceed loss (L) for any trophic interaction to be sustained and successful. G is measured in terms of energy or nutrient reward for prey acquisition, and L is the time or energy loss associated with acquisition, handling and digestion of prey (Luck, 1985). It can be argued that time losses can be translated to material and energy expenses asso-

ciated with maintenance metabolism during prey treatment.

When prey items are large and nutritionally rewarding with respect to relative prey:predator size, predators can afford to spend relatively large amounts of time and energy on activities associated with the L categories. However, when prey items are small or nutritionally less rewarding, then only when prey are highly abundant will $G > L$. Whiteflies fall into the latter case since they are at the smaller end of the size spectrum of insects (Byrne *et al.*, 1988). They are far smaller than nearly all of their potential predators (ca 1/125 the size of *G. punctipes*). However, since they are often very numerous in small patches (>400 adults/cotton leaf, DNB, unpublished observation), they offer potential as a rewarding prey item to certain predators.

The issue of small versus large prey raises questions of tradeoffs between predators' strategies oriented to energy maximization versus time minimization (Griffiths, 1980). The former term pertains to predators (often larval stages) that feed in a manner that maximizes the amount of energy gained per unit of feeding time. The latter applies to predators that require a fixed amount of energy. Once that energy is obtained, time minimizers spend the remainder of their time involved in non-feeding activities such as reproduction, growth and resting metabolism.

Based on our laboratory data, we assume that when whiteflies are very abundant, *G. punctipes* behaves according to the time minimizer paradigm, devoting approximately 2 h per day to handling prey and a negligible amount of time searching. Our observations under circumstances of extremely dense prey numbers are that only seconds are spent during intercatch interval and subduction; thus predator search time would be appreciable only as time devoted to patch location. The amount of prey extracted by *G. punctipes* is similar to that reported by Cohen (1989) with pea aphids as prey and by Cohen (1984) with lepidopteran eggs as prey. It seems that there is an upper limit to the amount that this predator will extract, regardless of prey species or life stage. However, in contrast with the amount eaten per

day, there are clear differences in extraction rates with small versus large prey. With aphids as prey, *G. punctipes*' extraction rate was ca. 230 ng s^{-1} (Cohen and Tang, in preparation) compared with a rate of 70 to 125 ng s^{-1} with whitefly adults as prey.

This study demonstrates that *G. punctipes* made no adjustment in handling time or in quantity of prey consumed according to the number of prey already consumed and the order of consumption (Table 1). There were no significant differences between the amount of time spent handling the first or the last prey nor in the amount of matter extracted from the first prey item through the tenth. This supports the interpretation that the amount of nutrient that can be extracted from each prey item is determined by constraints inherent in the prey and that these predators must consume a certain number of prey to reach a pre-set nutrient (or energy) requirement. However, when they reached that number (Fig. 1), they abandoned further search efforts. When prey were offered *ad libitum*, *G. punctipes* spent a maximum of 2 h per day searching for and handling prey.

The first criterion of predator/prey suitability – prey acceptance – was met in this experiment since *G. punctipes* readily attacked adult *B. tabaci* and in no choice tests consumed several prey items in succession. Attacks, in part of this experiment, were made by *G. punctipes* that were reared on artificial diet and had no opportunity to feed previously on whiteflies. Our objectives were not to determine rates of successful attacks, but preliminary observations led us to believe that such rates are high for *G. punctipes* as a predator of *B. tabaci*. We did note that failed attacks were most frequent when initial labial contact was with the prey's wings.

The gross nutritional profit (GNP), illustrated in Figure 2, in adult female whiteflies was similar to the GNP of *Heliothis virescens* L. eggs that were demonstrated by Cohen and Debolt (1983) to be an optimal diet for *G. punctipes*. The lipid content of the whiteflies was considerably higher than that found in pea aphids (Cohen, 1989). In these aphids, lipids accounted for less than 10% of the dry weight. The high percentage (50%) of the dry

weight that lipids account for in whiteflies is in part the result of the fact that aleyrodids are covered with lipid ribbons produced by glands (Byrne & Hadley, 1988). However, the surface lipids accounted for only 10% of the total dry weight (20% of the lipid weight). These surface lipids are not available as food for *G. punctipes* because of their mode of feeding on internal structures (Cohen, 1990). Therefore, they were subtracted from the total measured lipids, still leaving a considerable proportion of lipids compared with pea aphids, another homopteran with a putatively similar feeding target. Protein contents of whiteflies was similar to that of pea aphids, but the carbohydrate percentage appeared considerably lower than that of pea aphids.

We would expect a generalized predator to be adapted to varying concentrations of nutritional components in the different insects they utilize as prey. The contrasts in prey quality seen here, however, must have an impact on predator success or on search strategies. If these predators employ a nutrient self-selection strategy (e.g. Greenstone, 1980; Cohen *et al.*, 1988), they would derive ample lipid reward in consuming whiteflies. In contrast, the lipid reward of aphids is paltry. Thus, whitefly females provide *G. punctipes* a nutritional reward that is similar to *H. virescens* eggs and are, therefore, to be considered a potentially valuable food source for *G. punctipes* or any other predator that is nutritionally adapted to egg consumption.

The reward for consumption of an individual whitefly only amounts to about $12 \mu\text{g}$ of dry weight material. Compared to the consumption of a pea aphid that provides approximately $360 \mu\text{g}$ dry weight (Cohen & Tang, in prep.). This appears to be a meager reward. However, the abundance of whiteflies could compensate for the small reward per prey item. Our studies reveal that the mean consumption of *B. tabaci* was approximately 36 individuals per day when 50 prey were provided. This amounts to consumption of approximately $430 \mu\text{g}$ per day (Fig. 2).

The daily metabolic cost of searching is 0.188 J h^{-1} for *G. punctipes* (Cohen, 1984). The reward for consuming each whitefly is about

0.163 J (7.48 μg for each whitefly consumed times 0.021 J μg^{-1} for a mixture of fat, carbohydrate and protein in the proportions reported here and the energy values for these nutrients according to Schmidt-Nielsen [1979]). Thus the daily reward for consumption of 36 whiteflies is 5.9 J while the metabolic and waste product losses are 3.8 and 0.4 J per day. Thus the energetic profit above maintenance amounts to approximately 2.2 J that can be devoted to biomass accretion. At this rate, it would take an adult *G. punctipes* about 10 days to accumulate the energy and material equivalent to 40 eggs (Cohen, 1984) per female. Cohen & Debolt (1983) demonstrated that *G. punctipes* produce approximately 5 eggs per day under optimal conditions; so it appears that whitefly adults are an energetically feasible source of nutrition for *G. punctipes*.

We have used behavioral, nutritional and ecological criteria in our experiments to determine the potential of *G. punctipes* as a whitefly predator. We realize that this does not predict success in the field, but it does establish potential. This study goes further, however, than simple prey acceptance tests frequently used to screen potential predators; thus it should have stronger predictive value than less-thorough tests. Once the types of tests described here are conducted, intense field testing of the predator can be completed with candidates that show potential. The pre-screening techniques described here can serve as an objective set of criteria for assessment of potential predators. It also adds information about a potentially valuable agent of whitefly control that is already established in areas of concern about whiteflies. It seems from this study that conservation of *G. punctipes* as well as augmentation may be a valuable contribution to control of *B. tabaci*.

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